Exoplanet Demographics Conference
November 9-13, 2020
Friday Talk Abstracts

Exoplanet Atmosphere Demographics

A Review of the Exoplanet Atmosphere Demographics - Johanna Barstow (UCL)

On the Taxonomy of Exoplanets Using Transmission Color Analysis - Kristin Sotzen (JHU)

The majority of exoplanets found to date have been discovered via the transit method, and transmission and emission spectra represent the primary method of studying these distant worlds. Current methods of characterizing transiting exoplanets entail the use of spectrographs on large telescopes, requiring significant observation time to study each planet. However, Crow et al (2011) showed that color-color reflectance ratios can be used to broadly categorize solar system bodies, and Sing et al (2016) and Stevenson (2016) showed trends in hot Jupiter water abundances as a function of blue-optical vs NIR/MIR altitude differences and temperature/gravity respectively. Batalha et al (2018) also showed that it is possible to classify giant planets in color-color space using WFIRST-like filters for planets that do not have significant cloud coverage. Grenfell et al (2020) went on to show the utility of transmission depth differences for the filters of the PLAnetary Transits and Oscilllations of stars (PLATO) mission, showing that basic atmospheric types (primary and water-dominated) and the presence of sub-micron hazes could be distinguished for some planets.

Building on these concepts, we are investigating the use of transmission color-color analysis for coarse categorization of exoplanets as well as assessing the nature and habitability of these worlds, with a focus on resolving the mass/radius degeneracy to aid in discriminating super-Earths and sub-Neptunes. We will present our results, including spectrum models, model comparison frameworks, and waveband selection criteria.

This method could allow for broad characterization of a large number of planets much more efficiently than current methods permit. For example, a TESS follow-on mission could observe multiple band transits to identify exoplanets by category and to break degeneracies between planet size and density (e.g., rocky vs icy). Additionally, data collected via this method could inform follow-up observing time of large telescopes for more detailed study of worlds of interest.

Finally, these data could be used to study planetary system structure for different types and ages of stars, with potentially significant impact to our understanding of planetary system formation and evolution.

Understanding the Radius Valley as a by-product of Planet Formation: Observational Signatures of the Core-Powered Mass-Loss Mechanism - Akash Gupta (UCLA)

Observations have revealed a lack of planets of sizes ~1.5-2.0 Earth radii, i.e. a radius 'valley' in the size distribution of small, short-period exoplanets. This observation has been typically attributed to atmospheric mass-loss due to photoevaporation. However, in recent work, Ginzburg et al. (2018) and Gupta and Schlichting (2019, 2020) have demonstrated that atmospheric mass-loss, powered by the cooling luminosity of the planetary core, yields a valley in the exoplanet size distribution, even in the absence of any photoevaporation or any other process. In my talk, I will describe the key physical processes that drive this core-powered mass-loss mechanism, present detailed comparisons with observations and discuss our recent results that make testable predictions for the core-powered mass-loss mechanism as a function of stellar mass, metallicity and age. I will show that, consistent with observations, the core-powered mass-loss mechanism produces a radius valley that moves to larger planet radii as a function of stellar mass. We thus find no evidence for a linear correlation between the planet and stellar mass, however, we can't rule it out either. Furthermore, under core-powered mass-loss, we find that planets typically lose the bulk of their atmospheres on ~ Gyr timescales to become super-Earths whereas under photoevaporation, this happens in the first ~ 100 Myr. We thus expect even ~ Gyr old planets to be undergoing atmospheric mass-loss. I will conclude with presenting expected atmospheric mass-loss rates among other observational tests to assess the importance of the core-powered mass-loss mechanism.

Unveiling the Planet Population at Birth - James Rogers (Imperial College London)

Recent Kepler data has shown that the radius distribution of small, close-in exoplanets is bimodal. Such bimodality was expected from photoevaporation models of close-in super-Earths, where some planets are stripped of their primordial H/He atmospheres, whilst others retain them. We present a hierarchical inference model on the distribution of Kepler planets using the photoevaporation evolution model. This approach is used to place key constraints on the planetary distributions for core composition, core mass and initial envelope mass-fraction, as well as test other models of planet evolution such as core-powered mass-loss. This new information has interesting implications on planet formation models and also hints at additional atmospheric mass-loss mechanisms.

To Cool is to Keep: Residual H/He Atmospheres of Super-Earths and sub-Neptunes - William Misener (UCLA)

Current theory predicts that observed rocky super-Earths accreted large nebular hydrogen/helium envelopes before disk dispersal. These atmospheres have since been mostly lost through hydrodynamic outflows. Such super-Earth atmospheres may soon be observable, but their mass, composition, and redox state resulting from their evolution are largely unexplored, despite these processes' potential impact on habitability. I will present the observable outcomes of the evolution of super-Earths from their initial states since disk dispersal. Using theoretical models, I will demonstrate that loss of the primordial atmosphere can be incomplete, leading to a thin residual H/He envelope. The masses of these remnant atmospheres vary by orders of magnitude depending on the planet's mass and the flux it receives from its host star. Super-Earths finish mass loss with atmospheric masses ranging from 10^-9 to 10^-2 planet masses for typical parameters. I will discuss the implications of this residual hydrogen for subsequent secondary atmospheres, including their masses, composition, and observational signatures.

Future Exoplanet Demographics Missions

Introduction to the Capabillities of Future Missions: Webb, Roman, Rubin, Euclid, ARIEL, PLATO - various speakers

Roman: Direct-imaging in Reflected Starlight with NGRST: Detectability of Confirmed Exoplanets and Population Analysis - Óscar Carrión-González (Technische Universität Berlin)

The Nancy Grace Roman Space Telescope (NGRST, formerly named WFIRST) will be the first mission to directly image exoplanets in reflected starlight. This will allow us to analyse cold and temperate exoplanets, which cannot be accessed by current facilities. So far, atmospheric characterization is achieved mainly through transit and occultation measurements, which biases these studies towards hot planets in close-in orbits. Direct-imaging observations of long-period planets in reflected starlight will increase our knowledge on the diversity of exoplanets and their atmospheres. This will also affect the theories explaining the formation and evolution of such planetary systems and their architectures. In this work, we studied the exoplanet detection yield of NGRST and future concepts such as LUVOIR or HabEx. For that, we explored the NASA Exoplanet Archive and computed, for all confirmed exoplanets, a range of possible orbital solutions based on their Keplerian parameters and corresponding uncertainties. From that, we obtained the probability of detection and the observational configurations in each case. We analysed the particularities of this subset of detectable exoplanets in comparison with other populations such as the transiting planets. In addition, we discussed the possibilities of retrieving atmospheric properties from direct-imaging measurements of these exoplanets and identified the most favourable targets for such studies.

Direct-imaging observations in reflected starlight are expected to be available in this decade. Here we conclude that NGRST will be able to detect a set of long-period exoplanets which is large enough to begin statistical studies of this population. This will help complete the big picture of exoplanet diversity. The coming years until this mission is launched should allow the community to define the most interesting targets to be observed and improve their orbital solutions.

Roman & Rubin: The Potential of Complementary Survey Strategies - Rachel Street (LCO)

The Nancy Grace Roman Space Telescope (NGRST) is scheduled to begin a survey of the Galactic Bulge mid-way through the all-southern-sky Legacy Survey of Space and Time (LSST) on the Rubin Observatory. The Rubin Observatory are now investigating a range of alternative survey strategies aimed at maximizing the overall science return, so it is timely to explore how the data from these two great observatories may be combined.

The goal of the NGRST Bulge survey is to conduct a census of the exoplanet population at separations from their host stars of ~1-10AU, and of free-floating planets, but constraints on its scheduling will lead to unavoidable gaps in the data timeseries of several months at least. I will discuss how LSST can complement this survey strategy to increase the fraction of planets discovered and fully characterized.

The Rubin Observatory will also detect microlensing events outside the Bulge in substantial numbers, allowing us to explore otherwise hidden populations in different Galactic environments and the Magellenic Clouds. I will discuss preparations to detect and characterize these events.

The Roman Galactic Exoplanet Survey: Predictions for the Free-Floating Planet Detection Rate - Samson Johnson (Ohio State Univ.)

The Nancy Grace Roman Space Telescope (Roman) will perform a Galactic Exoplanet Survey (RGES) to discover bound exoplanets with semi-major axes greater than 1 au using gravitational microlensing. Roman will even be sensitive to planetary mass objects that are not gravitationally bound to any host star. Such free-floating planetary mass objects (FFPs) will be detected as isolated microlensing events with timescales shorter than a few days. A measurement of the abundance and mass function of FFPs is a powerful diagnostic of the formation and evolution of planetary systems, as well as the physics of the formation of isolated objects via direct collapse. Roman will be sensitive to FFP lenses that have masses from that of Mars (0.1 M_Earth) to gas giants (roughly greater than 100 M_Earth) as isolated lensing events with timescales from a few hours to several tens of days, respectively. The number of detections will depend on the abundance of such FFPs as a function of mass, which is at present poorly constrained. Assuming that FFPs follow the fiducial mass function of cold, bound planets adapted from Cassan et al. 2012, we estimate that Roman will detect ~250 FFPs with masses down to that of Mars (including ~60 with masses < 1M_Earth). Roman will improve the upper limits on FFP populations by at least an order of magnitude compared to currently-existing constraints.

Constraining Formation Pathways for Widely-Separated Companions with JWST - Arthur Adams (Univ. of Michigan)

The formation histories of many directly imaged companions are still highly uncertain. Of specific interest are objects within a range of masses, relative to their primaries, which separates those that likely form via planetary pathways, and those which likely form via stellar pathways. Accurate constraints on the compositions of objects with these intermediate mass ratios, specifically their bulk C/O ratios, will help distinguish their formation histories. We present ongoing work to develop accurate retrieval tools for directly imaged sub-stellar companions. Our particular focus is on young imaged L-type companions, whose accurate atmospheric retrieval presents a greater challenge than their cooler T-type counterparts. Nevertheless, with appropriate tools such objects will be characterizable with JWST, whose capabilities complement ongoing ground-based observations.

Atmospheric Characterization of Exoplanet Populations with the James Webb Space Telescope - Knicole Colon (NASA GSFC)

The number of known exoplanets has skyrocketed over the past decade, thanks in large part to the Kepler and K2 missions and the Transiting Exoplanet Survey Satellite (TESS). From these missions, thousands of exoplanets and candidates have been discovered and distinct populations of exoplanets have emerged. One key way to understand different populations of exoplanets is to investigate the atmospheric properties of exoplanets, since the atmospheric composition of an exoplanet provides insight into its formation pathway. The James Webb Space Telescope (JWST), which is slated to launch in 2021, will offer unprecedented sensitivity enabling detailed studies of the atmospheres of transiting exoplanets in particular. In this presentation, I will provide an overview of JWST, including its current status, its capabilities for transiting exoplanet observations, and details about the goals, targets, and timelines of the Early Release Science (ERS) and Guaranteed Time Observations (GTO) transiting exoplanet programs. The ERS and GTO targets notably span a wide range of planet masses and temperatures, allowing us to explore a large parameter space and investigate how atmospheric properties correlate with other planet or stellar properties. Additional General Observer (GO) targets from the community will augment the ERS and GTO programs to provide an even more diverse population of exoplanets to study as well as additional opportunities for comparative exoplanetology. All together, we can expect to make significant progress in our understanding of the atmospheres of exoplanets and the formation pathways of different populations of exoplanets in the era of JWST.

ARIEL: The Pursuit of a Meticulous Chemical Survey of Exoplanet - Billy Edwards (UCL)

Thousands of exoplanets have now been discovered with a huge range of masses, sizes and orbits. However, the essential nature of these planets remains largely mysterious: there is no known, discernible pattern linking the presence, size, or orbital parameters of a planet to the nature of its parent star. We have little idea whether the chemistry of a planet is linked to its formation environment, or whether the type of host star drives the processes controlling the planet's birth and evolution.

Ariel, the ESA M4 mission which will launch in 2028, will characterise the atmospheres of ~1000 exoplanets with instruments providing simultaneous spectral coverage from 0.5-7.8 microns. By studying a large and diverse population of exoplanetary atmospheres, Ariel will offer profound insights into planetary formation and evolution within our galaxy. However, much work still needs to be completed to ensure Ariel is utilised effectively and efficiently. Current facilities and near-future

missions such as JWST can help shape our understanding of potential chemical trends and thus improve the observing strategy of Ariel. Developing strategies to exploit the synergies and complementarities between different facilities will be crucial in maximising the scientific yield of these missions.
I will present the latest study of potential targets for Ariel, discuss projects which seek to understand the key capabilities and niches of upcoming space-based observatories, and highlight areas which require additional investigation.

Panel on Synergy of Future Missions - various speakers